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DESIGN INPUT INDEX AS A PREDICTOR OF

PROJECT CHANGE BEHAVIOR

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DESIGN INPUT INDEX AS A PREDICTOR OF PROJECT CHANGE BEHAVIOR

by

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REPORT

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Stephen S. Bell

1 August 1991

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

PURPOSE

The purpose of this research was to investigate the relationship between Design Input Index, as developed by James A. Broaddus in his dissertation, Design Effectiveness in Construction: The Relationship Between Inputs to the Design Process and Project Success, and change behavior of military construction projects. Change behavior included investigation of total changes, the cost of changes, change categories which represent design errors and omissions, and unforeseen changes. The goal of this work was to develop a statistically-based mathematical model to predict change behavior on large Navy projects if the Design Input Index was known. Having a model would allow executives and managers within the Engineering Field Division and the Resident Officer in Charge of Construction to predict the number and category of changes which might occur on a given project. This tool would be very powerful in decisions regarding allocation of the limited resources within the organization.

SCOPE

This research studied 55 projects within the Southeast United States. These were the same projects that Broaddus used in his dissertation. The Design Input Index numbers he developed were compared with project change information provided by Southern Division, Naval Facilities Engineering Command. The only change categories considered in the analysis were those that indicate an error or omission in the

design, and unforeseen conditions. The total number of changes and their associated costs were also included. These categories were chosen from the many available because they tie directly into the idea that a more well defined project will have fewer changes required and fewer mistakes. The analysis centered on finding a suitable statistical model for each category that could be used to predict the value based on a known Design Input Index.

CHAPTER 2

THE NAVY AS AN OWNER

ORGANIZATION

Like all large corporations, the United States Navy has a large number of facilities that must be maintained for the operating forces to be able to carry out their varied missions. The Navy must have facilities for submarines, surface vessels, and aircraft. There are also requirements to provide and maintain facilities for logistics, communications and personnel support facilities such as commissaries, exchanges, recreation facilities, etc. To meet these requirements in a changing world, the Navy has a capital improvement program called the Military Construction Program (MILCON). This program typically involves approximately $2 billion per year. This program replaces old and inefficient facilities and provides facilities needed because of new or revised missions for the operating forces.[1] The Naval Facilities Engineering Command (NAVFAC) is the Navy's organization that administers and controls the MILCON Program. Figure 2-1 shows how NAVFAC fits in to the overall Department of Defense (DoD) and Navy organizations. NAVFAC is geographically organized into Engineering Field Divisions (EFD). These field divisions handle the actual accomplishment of major projects from conceptual planning through the final turnover to the using activity. Figure 2-2 is the Southern Division of NAVFAC Organization Chart.

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[1]James A. Broaddus, Design Effectiveness in Construction: The Relationship Between Inputs to the Design Process and Project Success, Unpublished Dissertation, University of Texas at Austin, May 1991, p. 30.

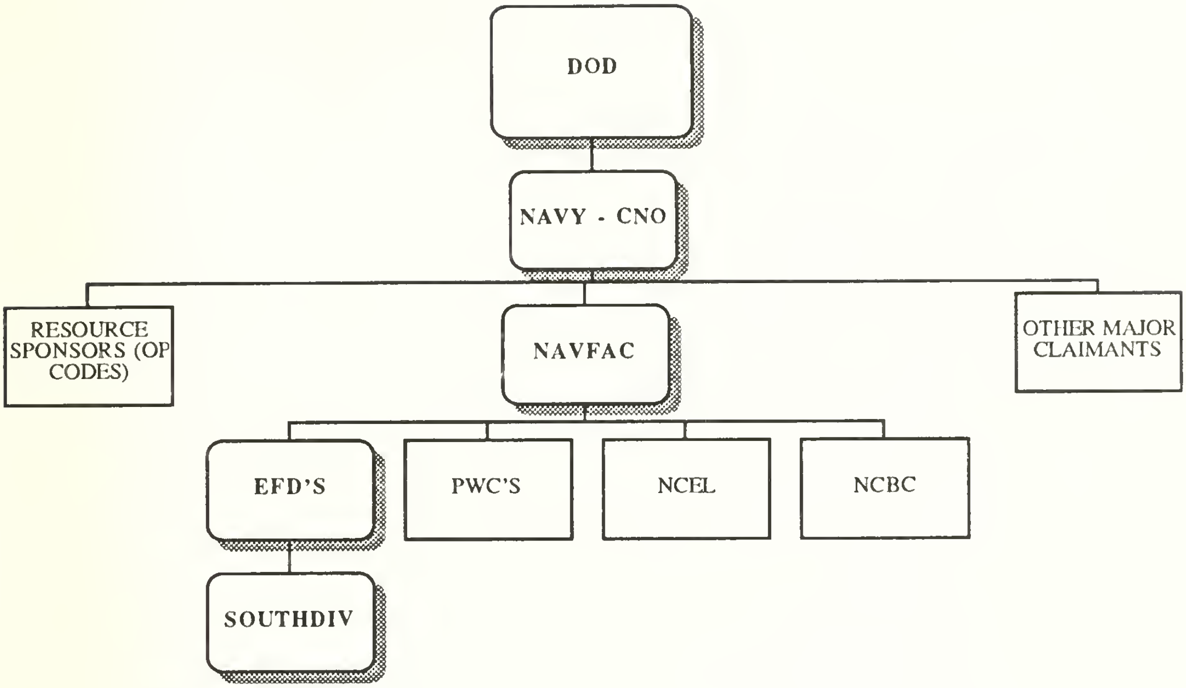

FIGURE 2-1: NAVFAC IN THE DEPARTMENT OF DEFENSE ORGANIZATION

All data used in this research came from the Southern Division of NAVFAC (SOUTHDIV). This EFD covers the geographic region in the Southern U. S. from South Carolina to New Mexico. It includes the states of South Carolina, Georgia, Tennessee, Florida, Alabama, Mississippi, Arkansas, Louisiana, Texas, Oklahoma, and New Mexico. There are 30 significant Navy shore installations, six Air Force bases and one Army activity within the area of responsibility. Most of the 1,000 people employed by SOUTHDIV are involved in conceptual planning, design, project

management, and construction activities. Most of those employees are based at the division's headquarters in Charleston, South Carolina.

The EFD organization is divided further into field offices that handle the administration of the contract for a project once it has been awarded. These offices are the Resident Officer in Charge of Construction (ROICC). Within the ROICC office, there is a project team that handles contract administration. This team consists of a Project Manager, who is either a Navy Civil Engineer Corps Officer or a GS-11/12 Civil Service engineer; a Construction Representative, who inspects the on-site work for conformance to project plans and specifications; and a Contract Specialist, who assists in handling the contractual matters associated with the project.

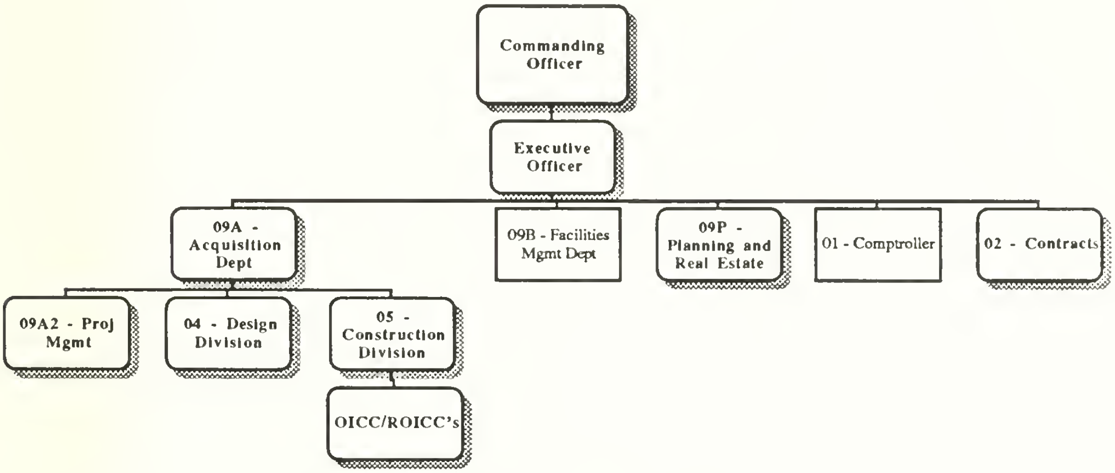

FIGURE 2-2: SOUTHERN DIVISION ORGANIZATION CHART

CONSTRUCTION PROCESS

The MILCON process begins years before any actual construction work is done on site. It starts with an activity having a requirement for a facility. This requirement can be generated locally at the affected base, or it may be generated by the needs of a new weapons system or a change in mission. After the requirement is identified, a project is submitted through the operational chain-of-command to the Chief of Naval Operations for validation. If the project is validated and is of high enough priority, it will become a part of the Six-Year Defense Program (SYDP). Not all Navy construction projects are a part of the MILCON process. In some instances, operations and maintenance funds may be used for construction, but the most complex and expensive projects performed are a part of the MILCON program. Each year, the Congress approves and funds each Navy new-construction project over $200,000 as an individual line-item of the Department of Defense's overall budget. This process is very competitive given the limited amount of funds available each year for overall defense spending.

When a project is within three years of its budget year, the planning process begins in earnest. Scope is defined further so that there is sufficient information available to progress with design authorization. In this stage, the EFD Planning Department has control of the project. Once the project is "Certified Ready for Design" and the project is within two years of its budget year, design of the project can begin.

The selection of the project A/E is based on qualifications per the Brooks Act, which is discussed later in this chapter. After the contract is negotiated, the A/E can

begin work on the detailed design. This period of the project is critical. The A/E must have the 35 percent design completed by the September that is 14 months before the project's scheduled budget year. If they do not meet this milestone, the project will either be pushed back two years or it may be cancelled in its entirety. This situation is driven by Congressional requirements.

With the 35 percent design complete, the project goes into the President's budget submission to the Congress for the DoD. It must then go through hearings within a number of subcommittees and committees within both houses of the Congress. If the project survives as a part of the Congressional budget process and is passed into law, it becomes legal for the Navy to enter into a contract to build the project.

CONTRACTING

There are several documents that implement Federal laws relating to construction within NAVFAC. These documents are part of a hierarchy, with the first having greatest power and the most generality. The lead document is the Federal Acquisition Regulations (FAR). These regulations govern all Federal procurement. The Department of Defense has a supplement to the FAR that publishes specific regulations pertaining to the DoD (DFARS). The Navy's supplement, the Navy Acquisition Procedures Supplement (NAPS), covers Navy-specific requirements. NAVFAC has its own Contracting Manual (P-68) which contains specific regulations applying to NAVFAC procurement. The standard method within NAVFAC and within the DoD for contracting for both A/E services and construction is the fixed-price contract.

A/E contracting is governed by the Brooks Act, which requires selection based on qualification with a contract price to be negotiated after selection is made. Price does not enter into consideration during the evaluation of a prospective A/E's qualifications. Generally, a change to the A/E contract will be negotiated at the start of construction for the designer to provide services such as submittal review during the construction period. The A/E is available as a resource for the ROICC in any questions regarding the design. A significant problem occurs with this contracting method during construction when changed conditions are encountered in the field or when the customer has a mission change requiring modification of the facility. Because of contracting regulations, a modification to the A/E contract must be negotiated before beginning design work required by a changed condition. This problem can result in delays in the field while the EFD negotiates the contract change with the A/E. Alternative contracting strategies, such as cost-plus design contracts, are allowed by the regulations, but their use is limited.

Construction contracts within NAVFAC are almost exclusively competitively-bid, fixed-price contracts. Any contractor with experience and sufficient financial strength may bid on NAVFAC work. There are certain special programs, such as the Small Business Administration Section 8(a) Program, which exclude some bidders. These programs are in place to encourage success in the targeted businesses. Most MILCON projects have a general contractor who coordinates construction of the facility. Since 1988, most MILCON projects are bid on an unrestricted basis. Previously, many large projects had been "set-aside" for small business accomplishment.

Administration of the construction contract after award is the responsibility of the ROICC. The ROICC's Project Manager is the contractor's primary contact with the Navy for the day-to-day construction business. The Contracting Officer is the official government representative to the contractor. He is the person who has the authority to obligate the government for any additional money or time that may arise out of a changed condition. This individual may be either a Civil Engineer Corps Officer or a Contract Specialist (1102 Series Civil Service employee).

CONSTRUCTION CHANGE PROCESSING

A formal procedure exists to handle changes on all NAVFAC construction contracts. The basic procedure is the same regardless of the amount of the change. Only the amount and detail of the documentation is different. What are called "change orders" in construction jargon are "Contract Modifications" to the government. A contract modification begins with a problem that is not covered within the contract. A letter from the contractor or a field observation starts the process. The Project Manager must do a quick estimate for the changed work to determine if there will be additional cost. At that point, he then makes a funding request through his Construction Area Manager in the Construction Division (Code 05) of the EFD. The Area Manager is a Civil Service engineer who is the central point of contact at the EFD for the ROICC. If the change is complex, the Project Manager also contacts the A/E to get design revisions for inclusion in the Request for Proposal (RFP) to the contractor.

After the contractor receives the RFP, he has a given amount of time to forward his proposal to the ROICC's Project Manager. Once the proposal is received, the

Project Manager and Contract Specialist, as a team, develop the Government Pre-negotiation Position for review and approval by the Contracting Officer. After the Contracting Officer's approval, they may then conduct negotiations with the contractor to determine a fair and reasonable price in money and time for the contract modification. Following completion of negotiations and the Contracting Officer's approval of the negotiated amount, a formal contract modification is signed by the Contracting Officer and the contractor. Field work may start after the modification is signed.

SOUTHERN DIVISION CONSTRUCTION MANAGEMENT SYSTEM

The Construction Management System (CMS) is the management information system used by the top executives within SOUTHDIV to track progress on all construction projects. An important component of the system, which has particular bearing on this research, is the modification tracking system. Each contract modification has a reason code that gives the executive a general explanation of why the change occurred. There are many category codes available.

Two of the codes are particularly associated with errors or omissions in the project design. "EROM" stands for "Error or Omission." This category is used if A/E liability for the change is being investigated or if the A/E has agreed to pay for part of the change work. "DSGN" stands for "Design Deficiency." It is used when there is a designer mistake or a design omission for which the A/E has been found not responsible. The category "UNFO" covers unforeseen conditions.

One problem that occurs with the coding system is the determination of A/E liability for a change. Both EROM and DSGN codes require a determination of A/E

liability for the changed condition. That is an extra step in the process of obtaining funds to execute a contract modification. In some cases, it is not obvious whether the A/E is liable. When that occurs, there can be delay in receipt of funds at the field level. On an item that has impact on the critical-path of a project, that delay can create entitlement to compensation for extended overhead expenses for the construction contractor. Delay costs are very expensive and they do not buy any additional construction.

Assignment of the reason code is normally made by the Construction Area Manager in Code 05 at SOUTHDIV. The code must be included in a request to Project Management (09A2) for funds to begin the modification process. The Project Manager in the field office may have input into the reason code, but the Area Manager makes the final determination. Sometimes, to speed up release of funds to the field, the Area Manager codes a change that perhaps could fall in the EROM or DSGN categories as UNFO. Coding the change UNFO eliminates the need for analysis to find out if the A/E is liable for the increased costs. This could cause the statistics reported by change code to be inaccurate.

CHAPTER 3

DESIGN INPUTS

Design is a very complex process that takes the owner's ideas and desires and transforms them into drawings and specifications that are used by a constructor to build the desired facility. Many decisions take place in this process that will affect the completed facility.

The Construction Industry Institute (CII) established the Design Task Force in the spring of 1984 to study the management of design. They organized their study into three general areas: inputs to the design process, the design process itself, and outputs of the design process.[2] In Publication 8-2, Input Variables Impacting Design Effectiveness, the task force identified the ten input variables having the greatest impact on design effectiveness. They are:[3]

- Scope Definition
- Owner Profile and Participation
- Project Objectives and Priorities
- Pre-Project Planning
- Basic Design Data
- Designer Qualification and Selection
- Project Manager Qualifications
- Construction Input

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[2]Construction Industry Institute Design Task Force, Evaluation of Design Effectiveness, Publication 8-1 (Austin, TX: Construction Industry Institute, 1986), p. 1.

[3]Construction Industry Institute Design Task Force, Input Variables Impacting Design Effectiveness, Publication 8-2 (Austin, TX: Construction Industry Institute, 1987), p. v.

- Type of Contract
- Equipment Sources

NAVFAC DEFINITIONS OF THE INPUT VARIABLES

The CII definitions of each of these terms were oriented toward private sector work. In his dissertation, Broaddus defined each of these variables in Navy terminology. The discussion that follows center on those definitions.

SCOPE DEFINITION

"Scope Definition" in the NAVFAC sense is the process of filling in project data listed on the Department of Defense Project Documentation Form (DD-1391). Theoretically, if the form is completed properly, the designer will have the information required to design the project efficiently and with minimum changes. Information required to complete the form includes size, functional requirements, budget, project requirements, etc. Unfortunately, this process does not always work as intended. Because of recent problems with this process, NAVFAC instituted a new program in 1988 to improve scope definition. This program is "Certified Ready for Design." This process is to take place before detailed design begins. It involves a comprehensive review of environmental impacts of a facility and numerous special features and requirements typical for the particular type of facility being considered. It includes any special construction considerations, long-lead item procurement, real estate and land acquisition issues, and seismic requirements. The scope needs to emphasize, or perhaps even prioritize, features required in case tradeoffs are required as the design develops. Ultimately, scope definition is a description of what the facility must do for

the user. It must be clear enough so the A/E can translate it into meaningful plans and specifications.[4]

OWNER PROFILE AND PARTICIPATION

Broaddus defined this input item as the "Participation of the facility user, major claimant and local activity in providing timely and accurate project requirements and in effective and consistent decision-making throughout the planning and design process."[5] This input variable is difficult. In the traditional sense, NAVFAC is the owner's representative, but the user, major claimant and local activity fulfill the role envisioned by the CII definition of this variable. They are responsible for executing their mission once the facility is completed. Changes in their mission requirements drive changes in the design, and their input is critical to ensuring the facility will satisfy their needs. NAVFAC's role is covered later under Project Manager Qualifications.

PRE-PROJECT PLANNING

The closest approximation of this input variable in NAVFAC is the project acquisition strategy. Broaddus defined it as the "Adequacy of the acquisition strategy for completing the project in an efficient manner..."[6] The acquisition strategy is the plan for construction and procurement that is determined at the EFD in the early stages of a project.

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[4]Broaddus, pp. 66-67.
[5]Ibid., p. 68.
[6]Ibid., p. 68.

PROJECT OBJECTIVES AND PRIORITIES

This input variable covers the project objectives that are most important to the user and major claimant. They are defined in terms of functional requirements, importance of aesthetics, project execution schedule, expandability, level of technology, initial operating date, etc.[7] There is no special effort to define specific project objectives in writing. The "Certified Ready for Design" program deals with objectives, but they are not specifically addressed. Usually, the main project objective for the user is to have the facility available when needed for some critical mission requirement.

BASIC DESIGN DATA

The adequacy of NAVFAC Guide Specifications, design manuals, and standard designs for a particular type facility are a part of this input variable. Also included is the adequacy of any user supplied basic data for unique or specialized-type facilities (i.e., process requirements, environmental controls, etc.), and the extent to which basic design data was beneficial and not a constraint to the design process.[8] NAVFAC's standard publications and guide specifications provide guidance to the A/E in the preparation of the design for a project. In some cases, the basic design data are out-of-date and prevent the A/E from specifying a newer, more efficient process or product in the facility.

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[7]Ibid., p. 69.
[8]Ibid., p. 70.

SELECTION AND QUALIFICATION OF DESIGNER

The selection of designers for NAVFAC projects falls within the Brooks Act. This law specifies that designers must be selected on the basis of technical merit and not cost considerations. A/E's are selected on technical performance, management ability, experience with similar projects, capacity to handle the work, etc. Only after selection is made is the pricing of services negotiated. This process generally produces a quality selection, but, because not all firms are alike, there is significant variance in performance by A/E's on NAVFAC projects.[9]

PROJECT MANAGER QUALIFICATION

Broaddus defined this input variable as the impact of the NAVFAC Engineering Field Division people assigned to the project, their qualifications, the consistency of personnel assigned (turnover), and their contribution to the project.[10] There is a Project Manager in Code 09A2 who is theoretically responsible for the project from conception to completion. However, during various phases of the process, certain other people exercise what would normally be thought of as project manager responsibilities. During the planning phase (conception to design authorization), the Head Planner is the lead. At design authorization, the project is turned over to the Project Manager, who takes it to completion. During the design phase, there is an Engineer-in-Charge in Code 04 (Design Division) who keeps up with the designer's progress and is the A/E's primary contact at the EFD. During Construction, the Construction Area Manager in Code 05 (Construction Division) is involved with

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[9] Ibid., pp. 70-71.
[10] Ibid., p. 71.

coordination at the EFD for the project. The final player is the ROICC. He is the Navy's representative to the construction contractor. He is responsible for the project execution in the field from award through completion and startup. Any evaluation of input variables is effected by all these players, so the definition includes the entire EFD project team.

CONSTRUCTION INPUT

This input variable is the thoroughness of construction input provided during the design phase from contractors, Construction Division personnel, and ROICC personnel concerning the availability of labor and materials, appropriate construction methods, sequencing of work, practical advice on field conditions, etc.[11] There is generally little construction input during the design phase of a project and the input that does occur comes very late in the process. A constructability program as advocated by CII is not in place. The Construction Area Manager and ROICC personnel review the design at various stages of completion and make written comments. The only review by contractors occurs after the project is out for bids and the contractors ask questions to clarify the designer's intent on a specific item or section of the project.

TYPE OF CONTRACT

Broaddus defined this variable as the effectiveness of the A/E contracting process (i.e., length of the contracting process and its impact on project schedule, methods for handling scope changes, Government design review procedures, level of responsibility and authority given to the designer, etc.).[12] The type of contract used for

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[11]Ibid., p. 72.
[12]Ibid., p. 72.

A/E services within NAVFAC is almost exclusively the fixed-price contract. This can have significant impact on project schedule if a change to the contract is required. Regulations require that a negotiated contract change be executed before any work by the A/E. This involves Contracts Department actions that sometimes include significant processing time. Sometimes this problem is overcome by the A/E proceeding with the work at his own risk, but the Government ends up paying for the A/E's risk. The trend is for more control of the process by Contract Specialists to ensure both Government and A/E compliance with current procurement regulations. New procedures may have impact on this input variable, but all 55 projects considered in this research were designed before the procedural changes took place.

EQUIPMENT SOURCES

This variable is the completeness, timeliness and firmness of vendor and Government furnished equipment data. The impact of this variable will depend on the type of project being considered. Generally, most commercial-type facilities do not have Government furnished equipment. All equipment is specified as part of the construction contract and the contractor handles all procurement. In some industrial facilities, the Government provides equipment and the accuracy of forecasts for this equipment can have an impact on design effectiveness. The Government must be able to give the A/E a manufacturer for a particular piece of equipment and the manufacturer must provide data regarding size, power requirements, etc., for the designer to complete the design. If this information is not accurate or is late, it could have an impact on the project schedule. Also, if equipment is a part of the construction contract, the specifications may not favor any particular manufacturer over another.

The specification must allow competition between equipment sources. This can sometimes make it difficult for the A/E to get the equipment he desired when he designed the facility. This is a problem area for NAVFAC.[13]

DESIGN INPUT INDEX

To tie all these input variables together and provide a meaningful research tool, Broaddus developed a questionnaire to quantify the impact of each of the input variables for the projects he studied. He used the objectives matrix technique and, in the process, developed a measure of design input called the Design Input Index. This index varied from 100 (very poor) to 1000 (superior). This research studied the same 55 projects as Broaddus and used his Design Input Index values for comparison with change information on those same projects. The objectives matrix technique is explained in great detail in CII Source Document 22, Objectives Matrix Values for Evaluation of Design Effectiveness, by John O. Stull, Jr. and Richard L. Tucker.

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[13]Ibid., p. 73.

CHAPTER 4

RESEARCH METHODOLOGY

DATA GATHERING

As mentioned in the previous chapter, data for Design Input Index came from Broaddus. Input index and general project information were placed in a spreadsheet in Microsoft Excel for use as a database in the analysis. Data for changes on those same projects came from Southern Division. This information was available directly from the Construction Management System database. It came in the form of a project printout with all changes listed by category, cost and description. Change category and cost figures were entered in the database for use in the analysis. Primary emphasis was on the number of changes in the EROM, DSGN and UNFO categories. EROM and DSGN were chosen because they reflect problems with the project design. Since Design Input Index is a measure of the quality of the design, the categories tied to the design should have some relationship with the input index. UNFO was chosen because of the assumption that a more well defined design should have fewer unforeseen conditions. Total changes, the total cost of changes on each project, and costs associated with each change category were also considered important because they gave some indication of the overall change behavior of the projects and tied an important asset, money, to the analysis. There was no further investigation into the specific work accomplished in each contract modification, because the emphasis of this research was on overall change behavior by change category.

ANALYSIS METHODS

The primary analysis methods were correlation analyses using least-squares principles. Several computer software packages were used for various parts of the analysis. StatWorks™ by Cricket Software, Inc. was the first package employed and was used for the statistical analysis. It provided information regarding the Coefficient of Determination, R^2, for each of the comparisons. To provide a check on StatWorks™ and to confirm the results, DeltaGraph™ by Deltapoint, Inc. was used. DeltaGraph™ also was used for the graphics in this report. Microsoft Excel was used for the database.

Statistical comparisons were made using the "curve fit" or "regression" options on both programs. The independent variable in the analysis was the Design Input Index for all projects and the dependent variable was number of changes or change cost for a specific category for all projects. The input index and change data for a specific project were matched together to create a data point in a two-dimensional plot. The initial focus of the study was to develop an easy to use linear model to relate design input index to changes on projects. Because of this, the first comparison done was a linear regression. Before any computer analysis could begin, the cutoff level for the coefficient of determination, R^2, had to be defined. From Young's Statistical Treatment of Experimental Data, there was a 10 percent probability that a R^2 value of 0.23 could be exceeded by random chance with 55 observations.[14] Since the sample for this research was 55 projects, a R^2 level of 0.23 could occur even if the variables being compared had no correlation. The value of the coefficient of determination for a

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[14]Hugh D. Young, Statistical Treatment of Experimental Data (New York: McGraw-Hill Book Company, Inc., 1962), p. 16.

model to show a minimal relationship in this research was set at 0.40. This cutoff point was selected so low because the data come from different projects with different management and ideas regarding the importance of the category coding system. The variables had to be related beyond that which could be expected because of random matching.

To do the analysis, StatWorks™ used the principles of least-squares. The program took the data sets for each comparison and fit the "best line" to the data. The assumptions made in the program follow those of standard least-squares theory.[15] The theory is explained in great detail in Draper and Smith's book, Applied Regression Analysis.[16] The concept most important to this research was that the R^2 value showed whether the variables being compared had a reasonably linear relationship. If two variables could have a perfect linear relationship, the R^2 value for the comparison of those two variables would be 1.0. In practice, and with data from different sources subject to personal biases, a value of 1.0 would be impossible. Based on the previous paragraph, a R^2 value of 0.23 could occur with 55 random observations, so if a value of 0.23 or below were to occur, that comparison would not have a linear relationship.

StatWorks™ can also do polynomial regressions. The program used least-squares principles for the polynomial analysis. Polynomial regressions of various degrees (2nd, 3rd and 4th) were also done on each data set. The program gave the same basic information about each polynomial comparison as it did for the linear

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[15]James Rafferty, Richard Norling, Robert Tamaru, Charles McMath and Dave Morganstein, StatWorks™ (Philadelphia, PA: Cricket Software, 1985), pp. 53-59.

[16]N. R. Draper and H. Smith, Applied Regression Analysis (New York: John Wiley & Sons, 1981), pp. 8-40.

regression analysis. The key statistic was R^2. The same cutoff level of 0.40 for a good model in linear regression was used in the polynomial analysis.

The final comparison done as part of the analysis was to see if a logarithmic curve would "fit" the data. To do this in StatWorks™, the data for the dependent variable had to be transformed to logarithm by the program. Once this step was complete, a linear regression could be done to define the curve. The results were the same as the linear regression done earlier. The coefficient of determination, R^2, was the important result. The value for determining whether the model was satisfactory was the same as for the linear regression.

CHAPTER 5

PRESENTATION OF DATA

The projects studied in this research were all within Southern Division of NAVFAC. They all had a dollar value over $2 million and were all finished or scheduled to finish within a one-year window around July 1990. The cutoff date for all information included in the analysis was July 1990. A detailed listing of the data in spreadsheet format is in the Appendix.

DESIGN INPUT INDEX

Design Input Index varied from a low value (worst) of 158 for the Electrical System Distribution Improvements at the Naval Shipyard, Charleston, South Carolina to a high value (best) of 800 for the Ship Berthing Improvements at Naval Station, Mayport, Florida. Figure 5-1 shows the variation in Design Input Index for the 55 projects. Each bar is a project. The average Design Input Index was 572.

CHANGE DATA

The total number of changes had a low value of 4 for three different projects. Those were the Drydock Pumphouse at Naval Shipyard, Charleston, South Carolina; the Reserve Training Center in Greenville, South Carolina; and the Magazines - Phase 1 in Ingleside, Texas. Figure 5-2 shows the variation in Total Changes.

The variation in the total cost of changes is shown in Figure 5-3. The low dollar-value of changes occurred on the Missile Magazines at Charleston Naval

Weapons Station. This project had a net credit back to the Government for changes of over $14,000. The high project was the Electrical System Distribution Improvements at Naval Shipyard, Charleston, South Carolina with a total change cost of $2.1 million on a contract originally awarded at $4.9 million. This project had a current value in July 1990 of $7 million.

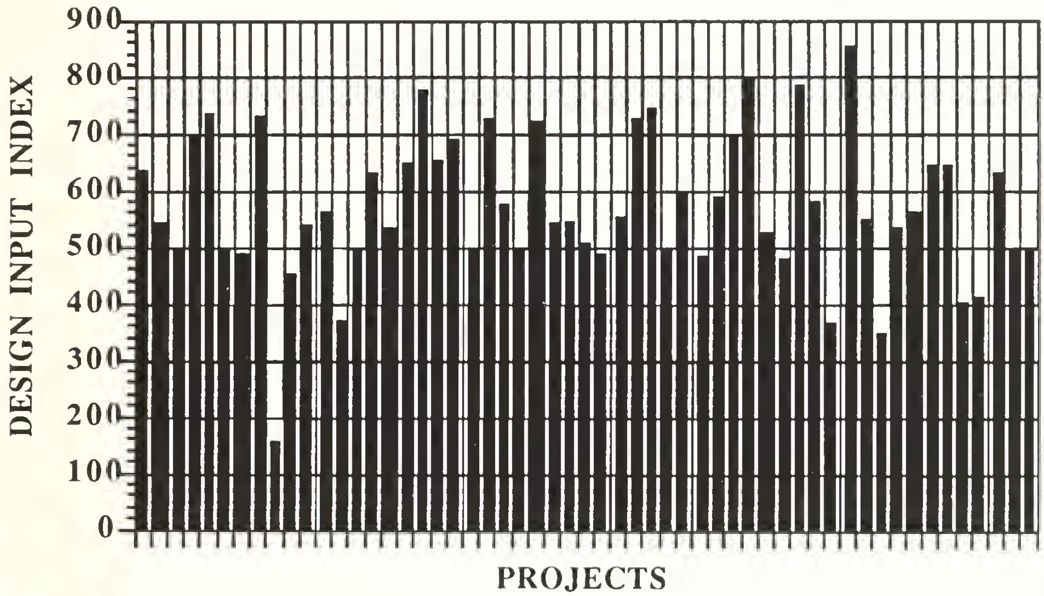

FIGURE 5-1: DESIGN INPUT INDEX

For the purposes of this research, changes in the EROM and DSGN categories were combined in the analysis. This was done because both categories concern design errors and the number of EROM changes was so small that no meaningful analysis could be done on that category alone. Figure 5-4 show the total number of EROM and DSGN changes. There were two projects that had no EROM or DSGN changes. They were the Headquarters Support and Telephone Building at Naval Station, Ingleside,

Texas and the T-45 Squadron Maintenance Facility at Naval Air Station, Kingsville, Texas. The project with the highest number of EROM and DSGN changes was the Aircraft Structural Repair Facility at the Naval Aviation Depot, Pensacola, Florida with 25.

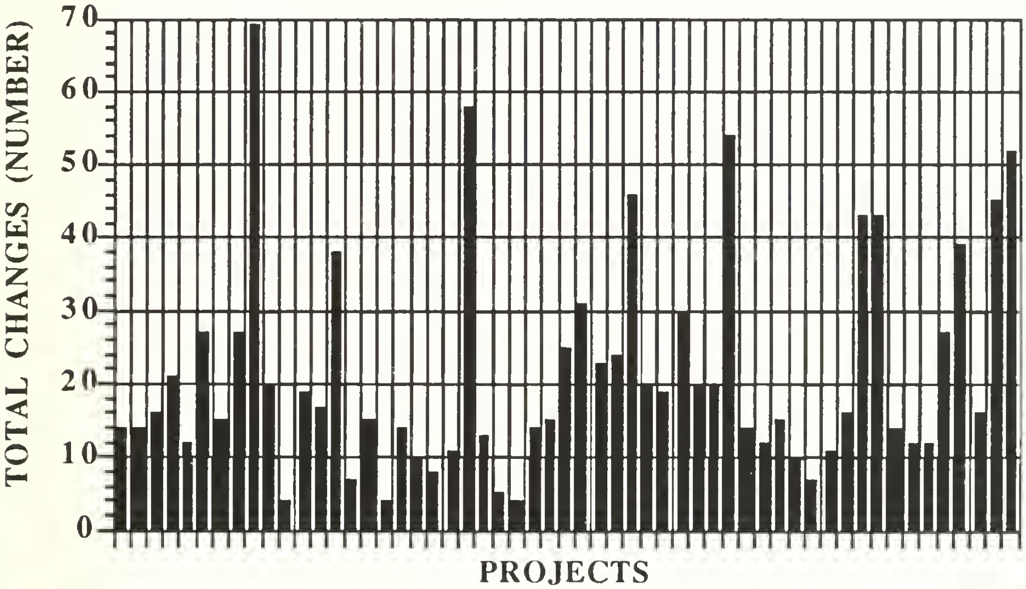

FIGURE 5-2: TOTAL CHANGES

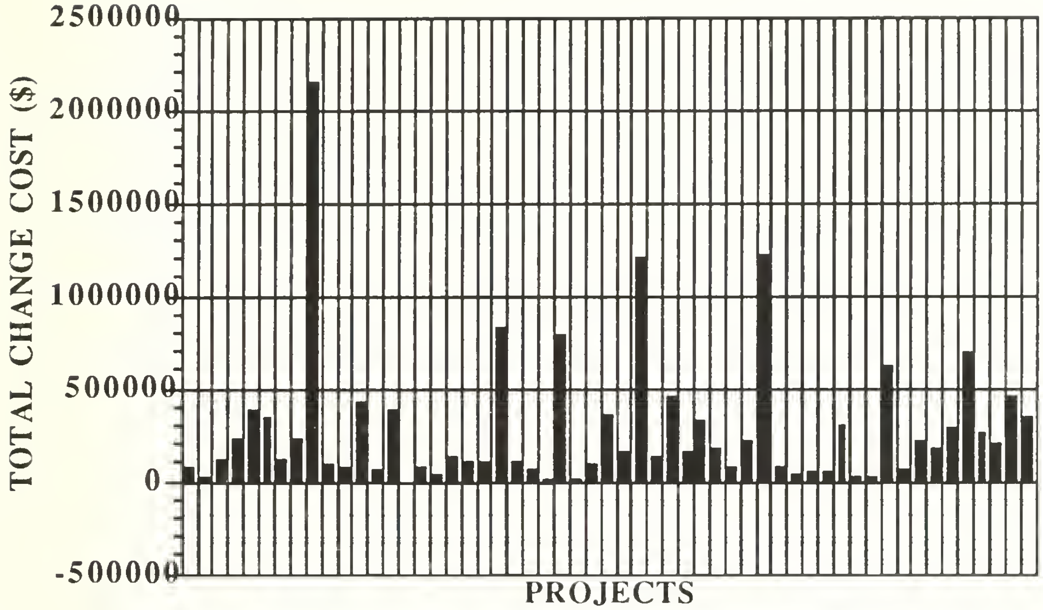

FIGURE 5-3: TOTAL CHANGE COST

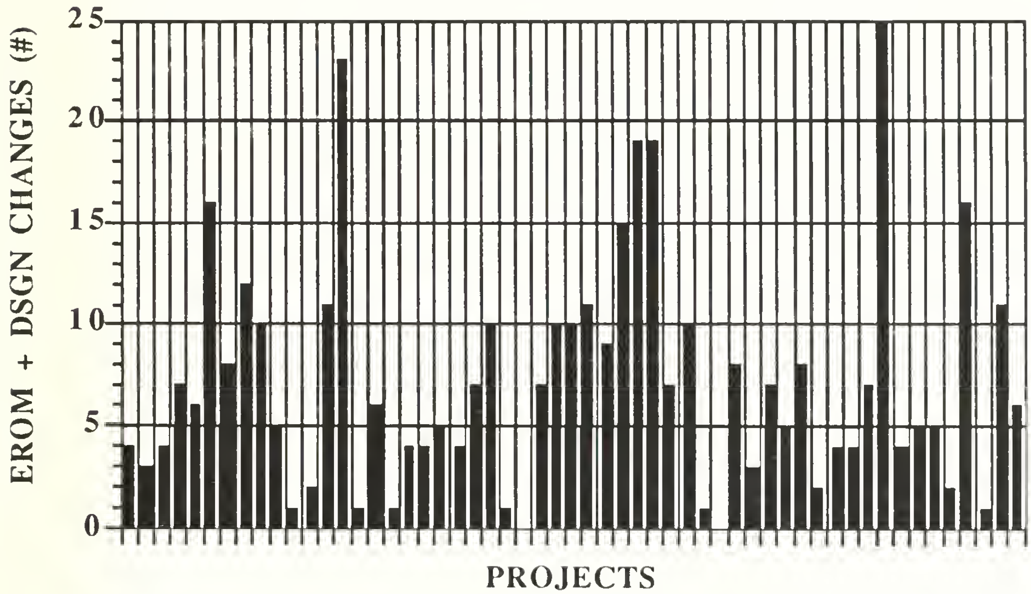

FIGURE 5-4: NUMBER OF EROM+DSGN CHANGES

The cost of EROM+DSGN changes is shown in Figure 5-5. The two projects with no EROM or DSGN changes also had no cost associated with those two categories. They were not the low projects, however. The Ship Support Complex at Naval Station, Ingleside, Texas had a EROM + DSGN cost that was a credit to the Government of $42,282. The high project was the Modifications to the Bachelor Enlisted Quarters at Marine Corps Air Station, Beaufort, South Carolina.

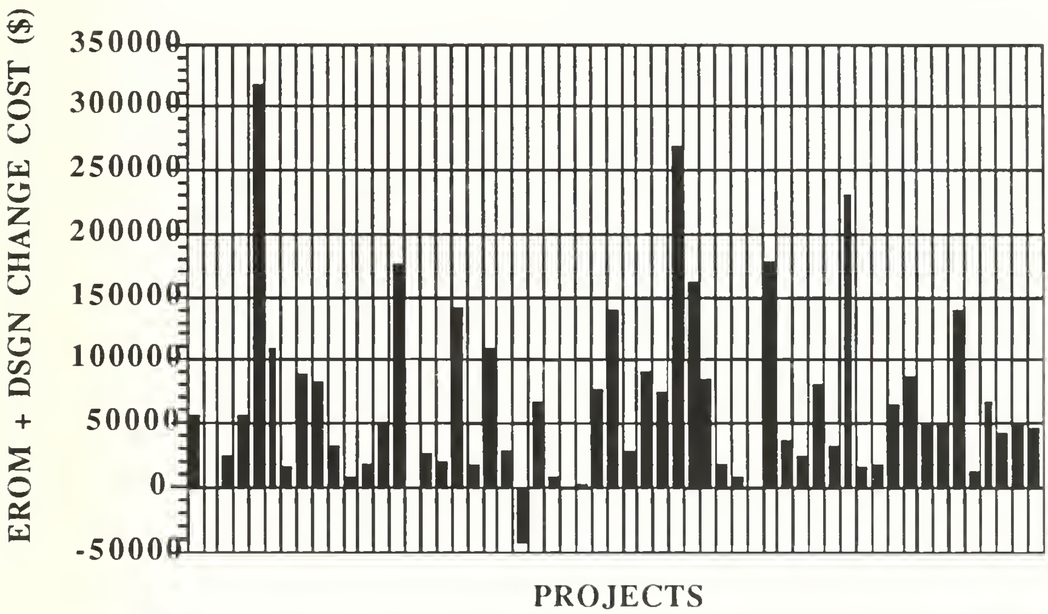

FIGURE 5-5: EROM + DSGN CHANGE COST

The total number of UNFO changes is shown in Figure 5-6. The project with the most UNFO changes was the Electrical System Distribution Improvements at the Naval Shipyard, Charleston, South Carolina. There were five projects that had no UNFO changes. They were the Missile Magazines at the Charleston Naval Weapons

Station; the Shore Intermediate Maintenance Activity at Naval Station, Ingleside, Texas; the Magazines - Phase 1 at Naval Station, Ingleside, Texas; the Storage Facility at the Naval Supply Center at Jacksonville, Florida; and the Aircraft Maintenance Hangar at Naval Air Station, Memphis, Tennessee.

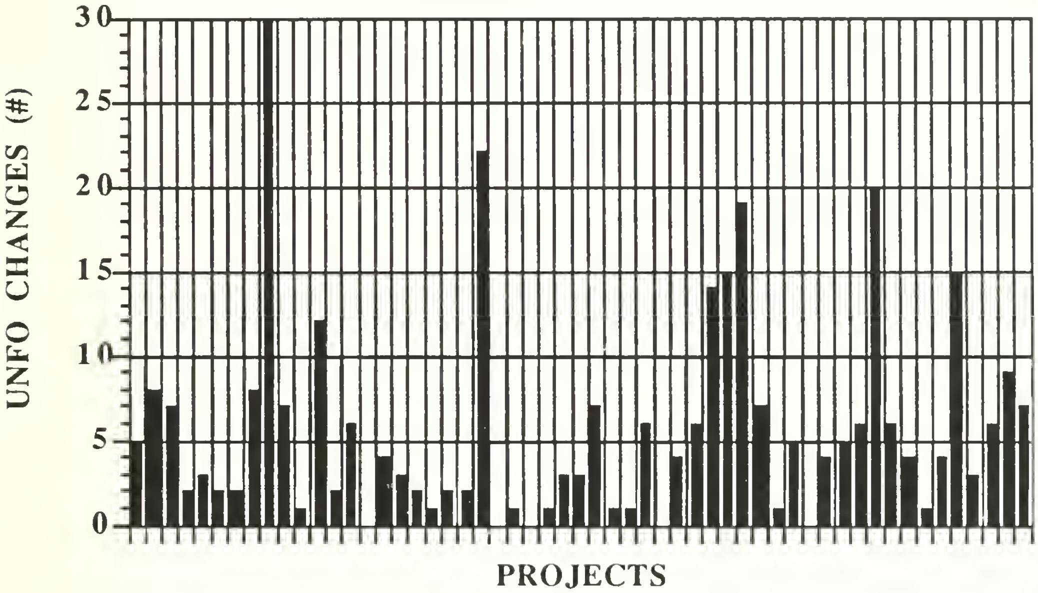

FIGURE 5-6: NUMBER OF UNFO CHANGES

The five projects previously listed with no UNFO changes also had no cost associated with that category, but they were not the low cost for this change code. The Underwater Research and Development Facility at Naval Coastal Systems Laboratory in Panama City, Florida was lowest with a credit to the Government of $67,051. The Electrical System Distribution Repair at the Naval Shipyard in Charleston, South

Carolina had the highest UNFO cost ($1.4 million). The UNFO change cost is shown in Figure 5-7.

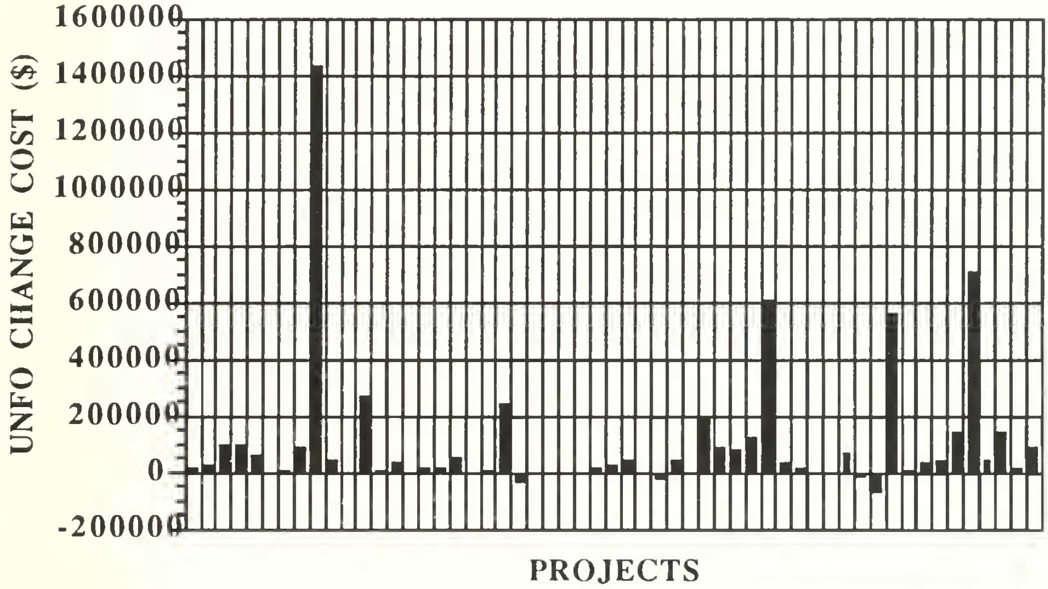

FIGURE 5-7: UNFO CHANGE COST

These figures show a graphical representation of the variables considered in the analysis. The complete spreadsheet with project names and the specific values for the different variables is included in the Appendix.

CHAPTER 6

ANALYSIS OF DATA

TOTAL NUMBER OF CHANGES

The data for Total Changes versus Input Index is shown in Figure 6-1. The scatter of the data prevented construction of a statistically significant model using regression techniques that could predict behavior of total number of changes with known Design Input Index. Linear, polynomial, and logarithmic analyses were done on the data. The coefficient of determination (R^2) for all fits was below 0.20. The data does have some value, however. Except for three projects, the total number of changes appeared to focus toward a lower number as input index increased. At lower input index, there was more scatter. This is an important result, because it tells the Navy that, with a low input index, the change results will be less known than if the input index is higher. With the focussing of the data, there should be fewer changes on the project. This focussing could be anticipated knowing the elements that make up the Design Input Index. With better project definition, experienced construction people would expect there to be fewer changes on the job.

TOTAL CHANGE COST

Figure 6-2 shows the data plot for Total Change Cost versus Design Input Index. Analysis of these data gave a very flat reading. The correlation for a linear fit was less than 0.09. The flatness of the data indicates that there is very little correlation between the cost of the total number of changes and the Design Input Index. While

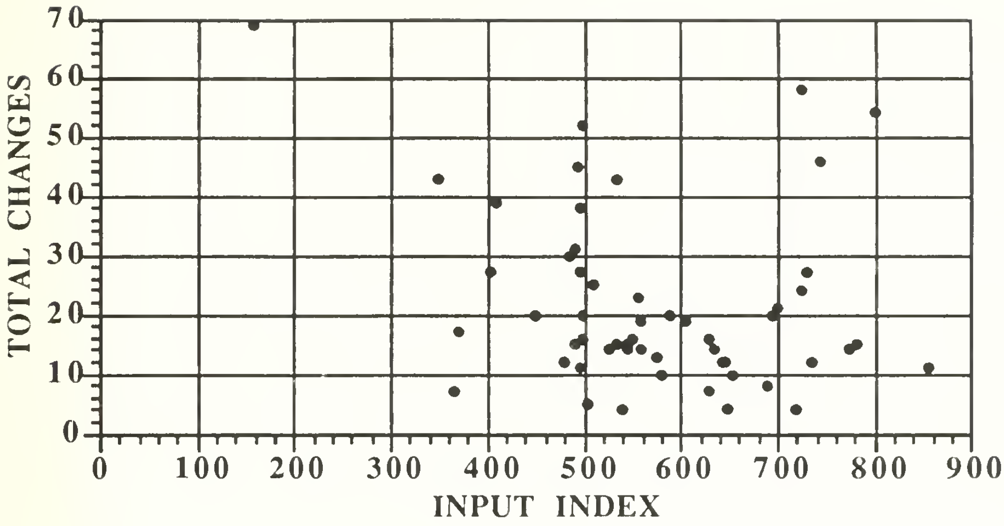

FIGURE 6-1: TOTAL OF CHANGES VS. DESIGN INPUT INDEX

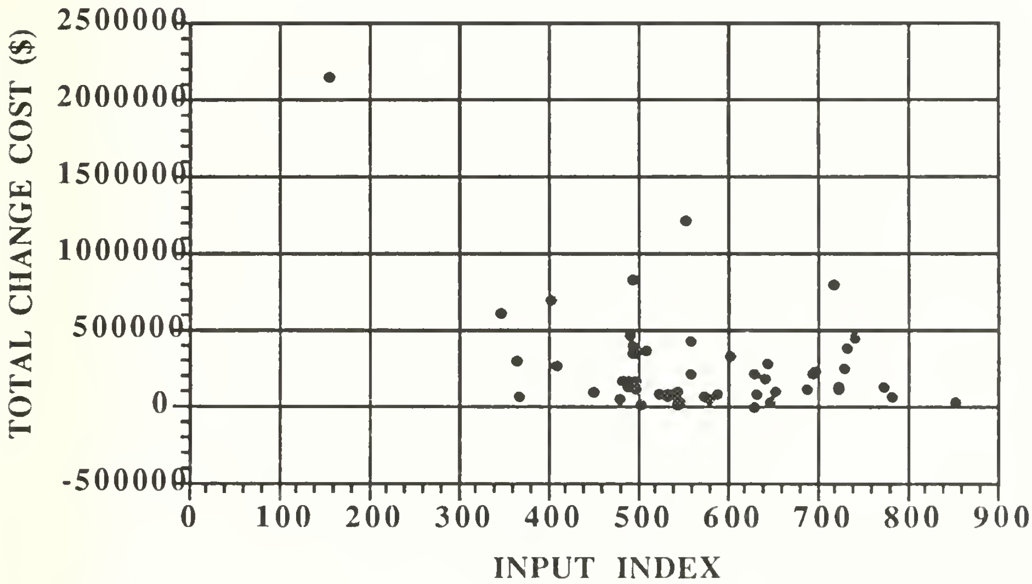

FIGURE 6-2: TOTAL CHANGE COST VS. DESIGN INPUT INDEX

there is more scatter in the plot at low input index, it is not substantial. Most of the data points are grouped below $500,000, regardless of their input index.

NUMBER OF EROM + DSGN CHANGES

The number of EROM + DSGN changes is shown plotted against Design Input Index in Figure 6-3. In this case, the data are scattered all over the graph. Coefficients of determination for this comparison were very low for all categories, so no statistical model could be developed using regression techniques. The same observation about the data for total number of changes holds true in this case also. The data has an

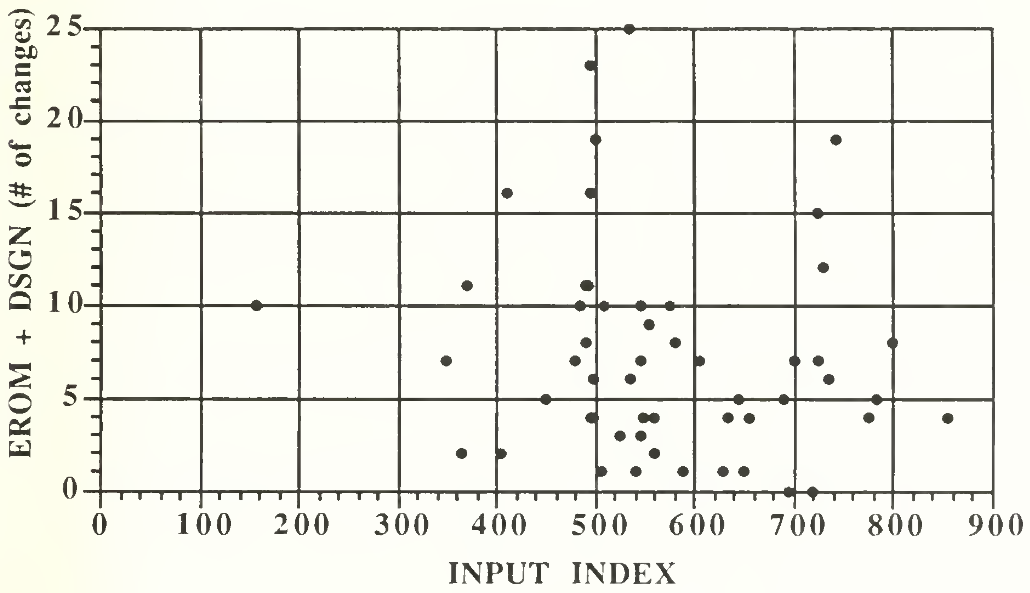

FIGURE 6-3: NUMBER OF EROM + DSGN CHANGES VS. DESIGN INPUT INDEX

apparent focus toward the low end of the cost scale, with the exception of three projects, when input index is increased. This is very important because it shows that it is possible that, if input index is increased, there will be fewer design-related changes during construction. Certainly there is more scatter, and therefore less certainty, at or below an input index of 500. Most of the focussing in this area occurs after the 500 level.

EROM + DSGN CHANGE COST

Analysis on the cost of EROM + DSGN changes versus the Design Input Index did not yield any statistically significant models. All coefficients of determination were

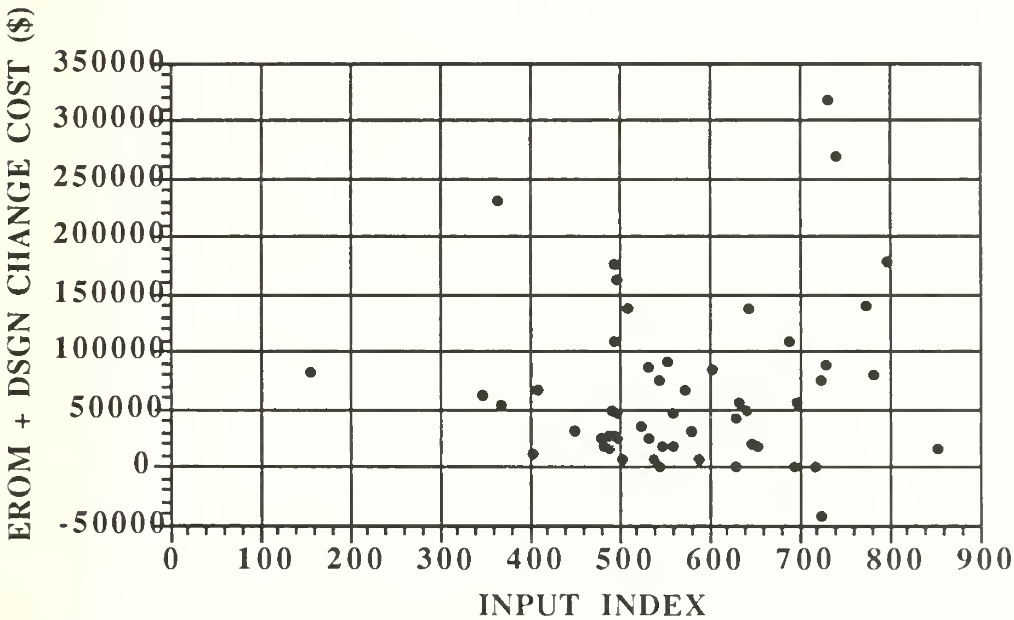

FIGURE 6-4: EROM + DSGN CHANGE COST VS. DESIGN INPUT INDEX

below 0.08 for linear and polynomial approaches. The data in this area is mostly grouped between zero and $150,000. There are some projects outside those bounds, but the majority are within them, regardless of input index. There is no apparent impact of higher input index on the cost of EROM + DSGN changes. Figure 6-4 shows the plot of EROM + DSGN cost versus input index.

NUMBER OF UNFO CHANGES

Figure 6-5 shows the number of UNFO changes against input index. Again, the statistical analyses did not give any significant results. Coefficients of

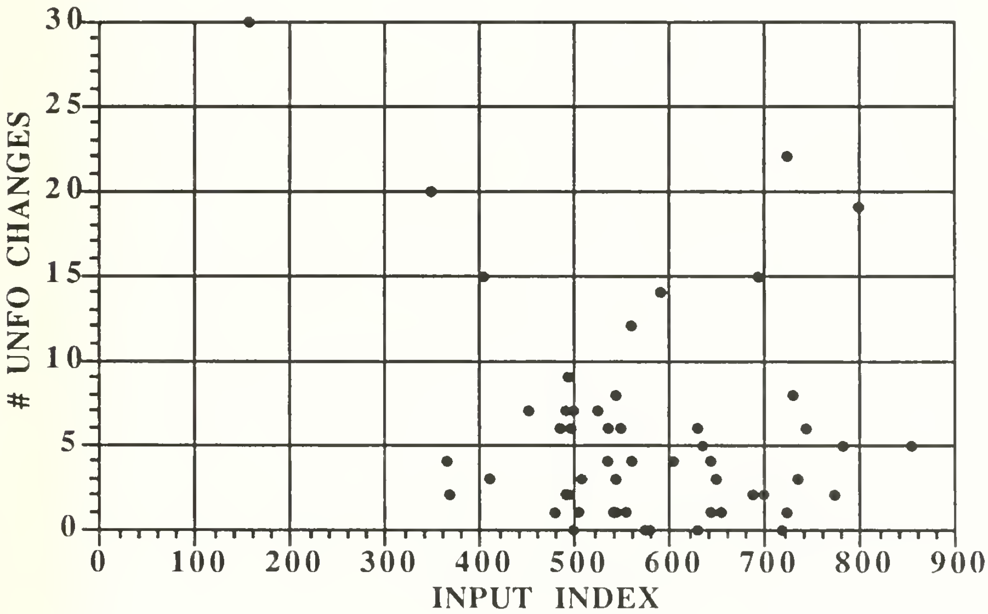

FIGURE 6-5: NUMBER OF UNFO CHANGES VS. DESIGN INPUT INDEX

determination were below 0.10 for all models. The same observations regarding focussing of data discussed before hold true for this category. The data tends to focus to the low end of the number of changes axis as the input index increases. This result could be anticipated knowing the make-up of the Design Input Index. As the project is more well defined, there should be fewer unforeseen problems.

COST OF UNFO CHANGES

The plot of UNFO change cost against input index turned out to be fairly flat (see Figure 6-6). Coefficients of determination for this category were all below 0.20, so there were no statistically significant models for the relationship between the two variables. The data tend to focus toward zero as input index increased. This result is a symptom of the items that make up the Design Input Index. As scope is defined better, as the owner/customer participates properly in the process, as objectives are defined clearly, etc., the project can be expected to have less unforeseen costs, because there are fewer items that can be called unforeseen. The planning process creates a mechanism where the project becomes more clear and the design can reflect actual conditions and technologies that the contractor can translate into a finished structure.

SUMMARY

In looking at total changes, the selected change categories and costs associated with them, no significant statistical models based on regression analysis could be developed from the data. The trends in the data can provide a guide to the benefits of increasing the value of the Design Input Index to projects. Though a mathematical model was not developed out of this analysis, the results are nonetheless valuable.

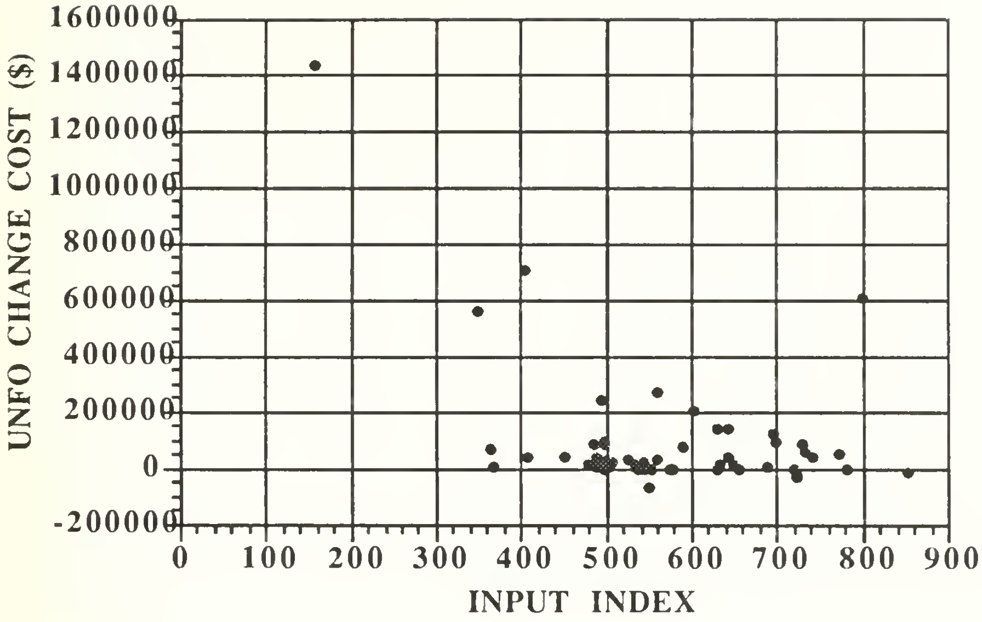

FIGURE 6-6: COST OF UNFO CHANGES VS. DESIGN INPUT INDEX

CHAPTER 7

CONCLUSIONS

1. The analysis did not yield a statistical model, based on regression analysis, for change behavior on NAVFAC projects based on the Design Input Index as formulated by Broaddus.

2. Design Input Index is a good relative measure of change behavior for projects within the Southern Division area. It will not give an exact statistical answer for the number of changes in each category to expect on a given project, but it is a good predictor of the order of magnitude of expected changes. The benefit to increasing the input index is to have more certainty about the order of magnitude of changes. At low input index, the change behavior could be anywhere from low to extremely high.

3. The trend shown in the analysis for total changes, number of EROM and DSGN changes, number of UNFO changes and the cost of UNFO changes of focussing toward low values as input index increases shows that knowing the Design Input Index is important. Knowing that value, the senior leadership in the organization can have a feel for the health of a given project. If input index is high, they are probably in good shape. If it is low, more effort needs to be made to define the items which make up the index.

4. Results of this analysis are useful for the ROICC in the field because they provide a guide for how a given project may turn out. Knowing Design Input Index, the ROICC or his senior representative can assign projects to Project Managers within

the office. Changes make up a majority of the Project Manager's work effort. If the ROICC knows the project may have a great many changes, he may want to assign that project to a more experienced individual. He can distribute the projects within the office to maximize the individual's experience and growth, but without sacrificing success of the project .

5. There is no apparent correlation between Design Input Index and the direct cost of changes for Total Changes and EROM + DSGN changes. Indirect costs to the government (preparation time for estimates, negotiations, etc.) are not currently quantifiable, but those items are a substantial portion of a ROICC Project Manager's job. Processing of contract modifications prevents the Project Manager from getting out into the field to observe and analyze their projects. The lack of direct correlation should not be taken as an indication that greater effort to improve the quality of design input would be wasted.

CHAPTER 8

RECOMMENDATIONS

ACTION BASED ON THIS RESEARCH

1. Because there is benefit in minimizing changes to projects in both time and money, NAVFAC should perform surveys to quantify Design Input Index for all projects in all phases of the design process. It should begin with the planning process and carry through until detailed design is completed. The design process milestone times currently in use would be ideal points to begin. Once Design Input Index is quantified, it should be used to identify problem projects early, so additional resources can be dedicated to make the project successful.

2. The coding of changes needs to be standardized better in all offices for the Construction Management System to be of more use to executives in the organization in tracking changes. The bureaucratic process for both EROM and DSGN changes needs to be streamlined so that a ROICC in the field does not have to code a change as UNFO just to get funds quickly to avoid delay damages. The A/E liability question should be pursued, but not at the expense of the project schedule. The EFD should fund the change up front and seek funds from the A/E after the fact if they were liable for the change.

3. There needs to be more training to familiarize people in the field with the different change categories and the importance of proper coding in the overall Construction Management System.

FUTURE RESEARCH

1. It would probably be beneficial to look into the issue of improper coding of changes to quantify the practice. Once the leaders of the organization know the scope of the problem, it can be corrected. These statistics are valuable tool to track projects, but if the reporting is inaccurate, those using them may make incorrect decisions.

2. Investigation of project schedule delays and their relationship with Design Input Index would be another area which could follow-on to both this work and that of Broaddus.

3. An investigation into where the design errors are made that are categorized as EROM or DSGN could tell NAVFAC where they need to concentrate more effort during the planning and design stages of projects.

CHAPTER 9

APPENDIX

Project Data

LOCATION	CONTRACT NO	PROJECT	CURRENT VALUE	INITIAL AWARD	INPUT INDEX	# EROM	EROM COST
ALBANY GA	84-0182	VENTILATION IMPROVEMENTS	$3,880,455	$3,807,714	635	0	$0.00
AMARILLO TX	86-0096	RESERVE TRAINING CENTER	$2,820,547	$2,799,970	545	0	$0.00
ANDROS ISLAND	87-0412	BACHELOR CIV QUARTERS	$2,855,330	$2,802,000	499	1	$14,363.00
BARKSDALE AFB LA	86-0641	UEPH	$5,832,271	$5,830,000	700	2	$54,841.00
BEAUFORT SC	86-0427	BEQ MOD	$2,157,368	$2,052,135	735	0	$0.00
CHARLESTON AFB SC	84-0270	CORROSION WASHRACK	$5,026,800	$4,686,000	495	2	($2,866.00)
CHARLESTON NS	87-0281	BACHELOR ENLISTED QUARTERS	$8,232,300	$8,109,000	490	0	$0.00
CHARLESTON NSC	86-0263	PROVISIONS WAREHOUSE	$4,776,850	$4,540,000	730	0	$0.00
CHARLESTON NSY	81-0215	ELEC SYSTEM DISTR IMPR	$7,003,384	$4,933,611	158	0	$0.00
CHARLESTON NSY	84-0111	HAZ/FLAM STOREHOUSE	$3,639,575	$3,549,000	451	0	$0.00
CHARLESTON NSY	84-1014	DRYDOCK PUMPHOUSE	$4,798,976	$4,727,000	540	1	$8,000.00
CHARLESTON NSY	85-0152	POWER PLANT MODIFICATIONS	$2,980,349	$2,720,000	560	0	$0.00
CHARLESTON NWS	86-0266	AMMO OVERHAUL SHOP	$2,894,082	$2,834,150	370	0	$0.00
CHARLESTON NWS	85-0604	CONSOLIDATED BRIG	$14,416,694	$14,028,000	496	2	$4,806.00
CHARLESTON NWS	87-0093	MISSILE MAGAZINES	$2,564,293	$2,578,357	630	0	$0.00
DALLAS NAS TX	86-0127	AIMD ADDITION	$2,699,793	$2,619,264	535	0	$0.00
GREENVILLE SC	86-0108	RESERVE TRAINING CENTER	$3,053,086	$3,020,000	650	1	$20,495.00
GULFPORT NCBC MS	84-1002	SEABEE EQUIPMENT WHSE	$13,085,972	$12,957,000	775	1	$97,983.00
GULFPORT NCBC MS	86-0020	HAZ MAT/FLAM WHSE	$2,719,655	$2,633,000	655	0	$0.00
GULFPORT NCBC MS	87-0467	CONTROLLED HUMIDITY WHSE	$4,670,639	$4,557,805	689	2	$99,614.94
HAWKINSVILLE GA	86-0073	SPACE SURVEILLANCE ANTENNA	$2,939,176	$2,144,000	495	0	$0.00
INGLESIDE TX	86-0288	SHIP SUPPORT COMPLEX	$48,400,180	$48,335,000	725	0	$0.00
INGLESIDE TX	86-0729	SIMA	$5,586,068	$5,532,000	575	0	$0.00
INGLESIDE TX	88-0045	HQ SUPPORT/TELEPHONE	$2,865,576	$2,857,000	505	0	$0.00
INGLESIDE TX	88-0048	MAGAZINES-PHASE I	$2,039,740	$2,037,500	720	0	$0.00
INGLESIDE TX	88-0091	WAREHOUSE	$3,418,063	$3,415,384	545	0	$0.00
INGLESIDE TX	86-0731	BEQ	$6,060,225	$5,498,000	545	0	$0.00
JAX NADEP FL	85-0631	ENGINE REWORK FACILITY	$10,334,772	$10,223,000	509	1	$4,302.00
JAX NADEP FL	86-0089	FUEL ACCESSORY OVERHAUL	$4,263,195	$4,094,000	490	0	$0.00
JAX NARDAC	81-0850	DATA PROCESSING CENTER	$9,043,603	$7,867,000	555	0	$0.00
JAX NAS	86-0875	OPTICAL TRAINER BUILDING	$6,162,904	$6,079,000	725	0	$0.00
JAX NAVHOSP	84-0283	HOSPITAL ADDITION	$15,720,247	$15,262,000	743	0	$0.00
JAX NSC	86-0090	STORAGE FACILITY	$3,860,269	$3,741,000	500	0	$0.00
KEESLER AFB MS	83-0827	BEQ	$9,053,713	$8,721,205	605	1	$0.00
KEESLER AFB MS	86-0118	SQUADRON OPERATIONS BLDG	$4,165,158	$3,998,858	485	3	$8,635.35
KEY WEST FL NAS	85-0141	PHM BERTHING PIERS	$9,743,539	$9,673,357	590	0	$0.00
KINGSVILLE NAS TX	86-0112	T-45 SQN MAINT FACILITY	$7,363,407	$7,149,000	695	0	$0.00
MAYPORT NS FL	83-0216	SHIP BERTHING IMPROVEMENTS	$10,772,480	$9,665,000	800	0	$0.00
MAYPORT NS FL	87-0011	INDUSTRIAL WASTE TREATMENT	$2,875,653	$2,795,955	525	0	$0.00
MEMPHIS NAS TN	83-0232	BRIG	$3,085,325	$2,957,500	480	0	$0.00
MEMPHIS NAS TN	85-0716	BARRACKS	$8,080,899	$8,025,000	783	1	$55,616.00
MEMPHIS NAS TN	83-0762	AIRCRAFT MAINT HANGAR	$3,502,314	$3,452,078	580	0	$0.00

CONTRACT NO	# DSGN	DSGN COST	# UNFO	UNFO COST	TOTAL CHANGES	TOTAL CHANGE COST
84-0182	4	$56,740.00	5	$17,278.00	14	$76,130.00
86-0096	3	$184.73	8	$21,000.26	14	$21,084.99
87-0412	3	$10,467.00	7	$98,316.00	16	$113,891.00
86-0641	5	$1,504.00	2	$93,069.37	21	$232,462.42
86-0427	6	$317,382.00	3	$60,351.00	12	$377,733.00
84-0270	14	$110,966.02	2	$3,000.00	27	$347,050.47
87-0281	8	$15,012.69	2	$7,435.24	15	$123,300.26
86-0263	12	$88,196.37	8	$87,297.24	27	$236,850.68
81-0215	10	$82,251.41	30	$1,436,560.50	69	$2,144,773.40
84-0111	5	$31,869.00	7	$37,809.00	20	$90,575.00
84-1014	0	$0.00	1	($729.00)	4	$71,976.00
85-0152	2	$17,900.00	12	$269,349.18	19	$429,449.18
86-0266	11	$52,975.00	2	$6,957.08	17	$59,932.08
85-0604	21	$170,812.00	6	$30,862.00	38	$389,483.00
87-0093	1	$286.45	0	$0.00	7	($14,063.18)
86-0127	6	$25,735.00	4	$12,414.00	15	$80,529.00
86-0108	0	$0.00	3	$12,591.00	4	$33,086.00
84-1002	3	$42,931.00	2	$55,535.00	14	$128,973.00
86-0020	4	$17,396.17	1	$417.00	10	$100,871.77
87-0467	3	$10,131.92	2	$3,087.61	8	$112,834.47
86-0073	4	$27,591.00	2	$239,050.00	11	$825,285.00
86-0288	7	($42,282.00)	22	($30,812.00)	58	$103,232.00
86-0729	10	$66,836.00	0	$0.00	13	$65,012.00
88-0045	1	$7,299.00	1	$1,777.00	5	$8,576.00
88-0048	0	$0.00	0	$0.00	4	$792,240.00
88-0091	7	$803.00	1	$500.00	14	$13,008.00
86-0731	10	$76,270.00	3	$16,007.00	15	$87,225.00
85-0631	9	$134,080.00	3	$24,907.00	25	$359,898.00
86-0089	11	$28,038.00	7	$38,809.00	31	$158,085.00
81-0850	9	$91,592.00	1	($1,678.00)	23	$1,207,253.00
86-0875	15	$75,026.00	1	($19,024.00)	24	$130,848.00
84-0283	19	$268,428.00	6	$38,185.00	46	$446,183.00
86-0090	19	$161,918.00	0	$0.00	20	$161,918.00
83-0827	6	$85,510.79	4	$204,999.00	19	$332,508.29
86-0118	7	$8,685.69	6	$84,584.43	30	$168,490.60
85-0141	1	$7,343.00	14	$76,551.00	20	$83,894.75
86-0112	0	$0.00	15	$121,632.94	20	$214,407.55
83-0216	8	$177,414.67	19	$601,312.00	54	$1,216,360.00
87-0011	3	$36,061.00	7	$33,915.00	14	$76,176.00
83-0232	7	$24,066.76	1	$11,952.00	12	$37,826.76
85-0716	4	$23,935.42	5	($3,839.85)	15	$55,899.57
83-0762	8	$32,057.12	0	$0.00	10	$50,236.33

LOCATION	CONTRACT NO	PROJECT	CURRENT VALUE	INITIAL AWARD	INPUT INDEX	# EROM	EROM COST
ORLANDO NTC FL	87-0040	UTILITIES IMPROVEMENT	$2,837,389	$2,463,000	365	0	$0.00
ORLANDO NTC FL	84-0999	WEAPONS TRAINING FACILITY	$2,501,565	$2,483,000	855	0	$0.00
PANAMA CITY NCSC FL	85-0450	UNDERWATER R & D FACILITY	$3,998,543	$3,974,780	550	0	$0.00
PASCAGOULA NSA MS	86-0405	REHAB BARRACKS A-PHASE I	$2,371,930	$1,756,000	350	0	$0.00
PENSACOLA NADEP FL	84-1010	AIRCRAFT STRUCT RPR FAC	$8,276,286	$8,213,000	535	0	$0.00
PENSACOLA NTTC	84-0404	INSTRUMENT TRNG FACILITY	$3,666,679	$3,453,000	560	0	$0.00
PENSACOLA NTTC	86-0223	COMPUTER OPERATIONS FAC	$4,593,836	$4,422,032	644	0	$0.00
PENSACOLA PWC	86-0558	INDUSTRIAL WASTE TREATMENT	$2,751,638	$2,472,000	645	0	$0.00
PENSACOLA PWC	83-0256	WATER SUPPLY ADDITION	$5,876,762	$5,182,000	405	0	$0.00
RIVIERA BEACH FL NRC	84-0349	RESERVE TRAINING BUILDING	$3,760,961	$3,594,318	410	4	$14,280.20
SHAW AFB SC	84-0004	ALTER UEPH	$4,306,878	$4,103,236	630	0	$0.00
SHAW AFB SC	84-0947	AIR FORCE HEADQUARTERS BLDG	$3,653,795	$3,196,000	494	0	$0.00
SHAW AFB SC	84-0069	BASE SUPPORT CENTER	$7,146,976	$6,847,000	498	0	$0.00
		TOTAL	$335,188,163	$321,466,209	572 (avg.)	22	$380,070.49

CONTRACT NO	# DSGN	DSGN COST	# UNFO	UNFO COST	TOTAL CHANGES	TOTAL CHANGE COST
87-0040	2	$231,014.00	4	$66,379.00	7	$297,393.00
84-0999	4	$16,452.48	5	($11,042.45)	11	$18,865.08
85-0450	4	$17,367.00	6	($67,051.00)	16	$23,763.00
86-0405	7	$63,461.20	20	$558,307.47	43	$615,930.32
84-1010	25	$86,295.69	6	$2,261.00	43	$67,311.00
84-0404	4	$47,881.60	4	$37,260.00	14	$217,141.60
86-0223	5	$49,350.65	1	$38,333.21	12	$180,046.47
86-0558	5	$138,175.50	4	$141,463.24	12	$279,638.74
83-0256	2	$11,436.00	15	$709,123.00	27	$694,762.00
84-0349	12	$51,646.63	3	$37,568.00	39	$252,795.54
84-0004	1	$42,000.00	6	$145,250.00	16	$203,642.00
84-0947	11	$48,631.00	9	$12,260.00	45	$457,795.71
84-0069	6	$46,845.00	7	$90,916.00	52	$346,676.00
	374	$3,193,970.96	315	$5,452,455.47	1191	$15,407,245.85

CHAPTER 10

GLOSSARY OF TERMS

CERTIFIED READY FOR DESIGN: A NAVFAC program to improve the quality of scope definition on Navy MILCON projects.

DESIGN INPUT INDEX: A measure of design effectiveness developed by James A. Broaddus in his doctoral dissertation which has a value from 100 (poor) to 1000 (superior).

DSGN: The NAVFAC contract modification reason code denoting a "Design Deficiency." This category is used when there is a designer mistake or a design omission for which the A/E has been found not responsible.

ENGINEERING FIELD DIVISION (EFD): A branch of NAVFAC which is responsible for execution of the facilities program within a defined geographic area. The EFD is responsible for planning and execution of the Military Construction Program for their area.

EROM: The NAVFAC contract modification reason code denoting an "error or omission" in the project design. This category is used if A/E liability for the change is being investigated or if the A/E has agreed to pay for part of the change work.

MILITARY CONSTRUCTION (MILCON) PROGRAM: The Navy shore facilities capital improvement program. All new construction projects with dollar value

over $200,000 are included in this program which is authorized annually by the Congress as a part of the Department of Defense budget.

NAVAL FACILITIES ENGINEERING COMMAND (NAVFAC): The engineering organization within the United States Navy responsible for all Navy shore facilities.

RESIDENT OFFICER IN CHARGE OF CONSTRUCTION (ROICC): The field office of the EFD responsible for actual field construction of new projects. They administer the construction contract after it is awarded.

SOUTHERN DIVISION (SOUTHDIV): The EFD responsible for the geographical region in Southern United States from South Carolina to New Mexico.

UNFO: The NAVFAC contract modification reason code denoting unforeseen conditions.

CHAPTER 11

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VITA

Stephen Spencer Bell was born in Bethesda, Maryland on August 15, 1961, the son of Annette Hudgens Bell and Warren Miller Bell. After graduating from Groveton High School in Fairfax County, Virginia, he entered the University of Virginia in Charlottesville, Virginia. He worked in the summers of 1981 and 1982 as a Civil Engineering Technician for the Federal Highway Administration in McLean, Virginia. He received the degree of Bachelor of Science in Civil Engineering from the University of Virginia in May of 1983. He was commissioned into the U. S. Navy Civil Engineer Corps in September 1983 as an Ensign.

His first duty assignment was with Naval Mobile Construction Battalion Seventy-Four. While with NMCB-74, he deployed to Sigonella, Italy as Detail Supply Officer, to Honduras as Detail Officer in Charge, and to Guam as Assistant Delta Company Commander and Engineering Officer. In July 1986, Lieutenant Bell transferred to duty as Officer in Charge of Construction Battalion Unit 407 at Naval Air Station, Corpus Christi, Texas. He was responsible for all operations of this 35-man Naval Construction Force Unit. In July 1988, he transferred to the Resident Officer in Charge of Construction at NAS Corpus Christi where he was Senior Assistant Resident Officer in Charge of Construction. He entered the Graduate School of the University of Texas at Austin in August 1990.

He is married to the former Susan Alicia Mast of Corpus Christi, Texas. She is a Texas-Ex and is also attending the Graduate School of the University of Texas at Austin. He is a Registered Professional Engineer in the State of Texas.

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Thesis
B3628 Bell
c.1 Design Input Index as a
predictor of project
change behavior.